Tracked Vehicle Grounding Study

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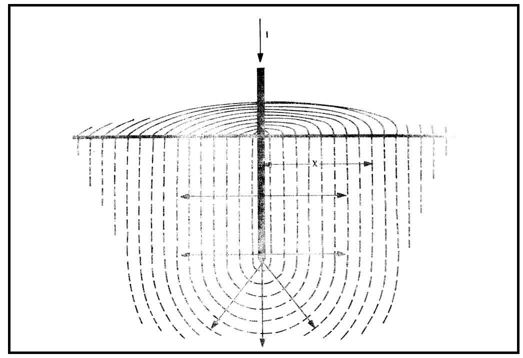
Abstract

The purpose of this paper is to investigate the suitability of vehicle tracks in providing a discharge path for fault current, signal noise control, and lightning protective grounding. Grounding equipment using the track pads is useful for a variety of industries including construction, mining, and defense applications. The scope of the paper is to present the method of the investigation and to grounding suitability results for tracked vehicles. The approach used is a study to derive the grounding equations from electromagnetic theory and predict the performance of the track pads, then comparing the results to actual ground resistance measurements taken on tracked vehicles.



Introduction

Grounding of mobile equipment is a major electrical safety concern for the U.S. Army Communications Electronics Command. As more advanced command, control communications and intelligence systems are fielded for tactical applications, the grounding problem proliferates. When these applications are made highly mobile, the emphasis of the design is to meet very stringent time requirements for system deployment. Also, the increased reliance on computerized systems has required cleaner, noise-free power systems. The grounding problem is increased from both causes because achievement of an effective ground is sometimes not possible given the stringent time requirements. Yet it becomes more necessary to ground, as cleaner power filters typically put currents on the equipment grounding conductor (neutral) sometimes in excess of published safety standards.

A Grounding Primer

Equipment is grounded for several reasons. The overriding safety concern is for electrical fault protection. In our equipment, mobile systems are typically powered by external, high output mobile generators. If the equipment grounding conductor should become open, a fault within the equipment could possibly create a potential on the surface of the equipment. Personnel contacting the equipment may find that they complete a circuit to the source of the current, the generator, through the earth. This current though the body can be harmful or even lethal. By grounding the equipment, we attempt to equalize the potential between the possibly energized equipment surface and the earth. The lower the resistance to ground is, the better we can accomplish this. Grounding systems, except in large fixed facilities, seldom achieve a very good ground. In this case, a current can possibly still flow through a person who completes the circuit as described above. But the current, which is inversely proportional to resistance, is lower and may avert harm. The other reasons for grounding are for lightning protection, and for noise control in signals. These reasons are ancillary to safety in our discussion and it stands that by achieving a good ground, we meet all three reasons. In our discussion, a "good ground" is one that achieves the minimal resistance to ground. The experiment we discuss attempts to achieve this ground connection through the tracks of a vehicle.

Basic Grounding Theory

Since we mentioned that the prime quality we seek in grounding system is minimal resistance, we explore it further. Resistance to ground is based on the ability of the earth electrode to transfer the current to the bulk earth surrounding it. It does this through a series of cylindrical shells, illustrated in the diagram at right. The important electrical characteristic that all grounding equations are dependent on, is the resistivity of the earth surrounding the electrode designated here by the symbol ρ. As a simple example, we can derive an approximate expression for the resistance to ground of a simple ground rod

$$i_x = \frac{I}{2pxl}$$

This expression yields the Current Density within earth as a function of x, the distance from the ground rod and l, the depth of the ground rod. Note that it is given by dividing the injection current by the surface area of the cylindrical shells about the earth electrode. It is in units of Amperes per unit area, as the injection current is expressed here as I. The current could be up to 200,000 amperes in a maximal lightning event.

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$$E_x = r\, i_x = \frac{rI}{2pxl}$$

From Ohm's law, electric field strength E, in units of volts per unit length may be found by multiplying the current density i by the soil resistivity, ρ .

$$V_x = \int_r^x E_x \, dx$$

We can then find the potential (voltage) as a function of x by integrating the field over x, the distance from the ground rod.

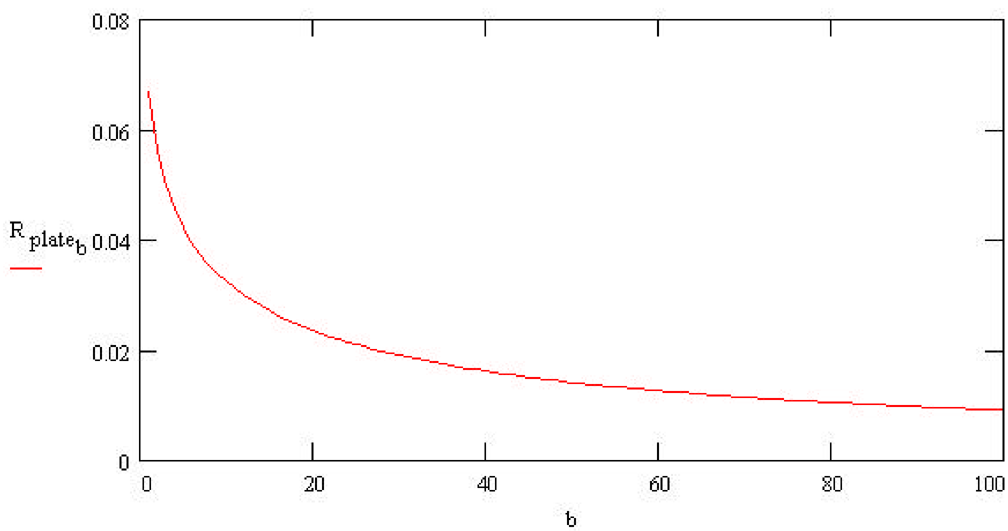
$$V_x = \frac{rI}{2pl}\int_r^x \frac{dx}{x}$$

We can substitute the electric field term E in the second equation, which yields the expression below, an approximate expression for the potential drop as a function of distance from the ground rod.

$$V_x = \frac{rI}{2pl}\ln x \ln r = \frac{rI}{2pl}\ln\frac{x}{r}$$

To find the resistance R, we apply Ohm's Law, dividing voltage by current, and using for limits of integration r=a (the radius of the cylindrical earth electrode) and x = 4l (a distance in which over 95% of the injection current is dissipated) yielding:

$R =$



Which is approximately the accepted theoretical value for ground rod resistance, unadjusted for soil inhomogeneity or other conduction effects.

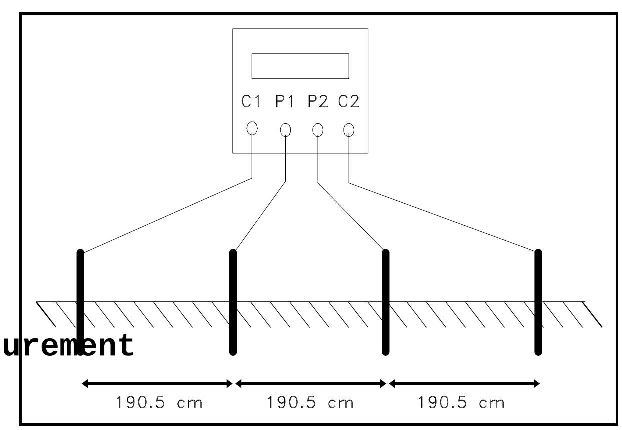
It is interesting to note the dependence of these equations on the surface area that the earth electrode has in contact with the ground. As a vehicle track has a large surface area in contact with the ground, we surmise that this may make an acceptable ground connection. It is also under significant pressure therefore it has a highly uniform contact. We can use the approximate resistance relation for a solid plate resting on the earth surface to estimate the resistance. Sparing the detailed derivation, the theoretical resistance is given by[1]:

$$R_{plate} = \frac{r}{p}\left[\frac{1}{a}\ln\left(\frac{a+\sqrt{a^2+b^2}}{b}\right)+\frac{1}{b}\ln\left(\frac{b+\sqrt{a^2+b^2}}{a}\right)+\frac{a}{3b^2}+\frac{b}{3a^2}\frac{(a^2+b^2)\sqrt{a^2+b^2}}{3a^2b^2}\right]$$

where a, b are the length and width of the plate, and ρ is soil resistivity. Plotting the theoretical resistance in figure 2 using this relation, we find that the resistance to earth levels off after about 100 centimeters, which is much shorter than the entire length of a typical vehicle track. We can also see that the resistance is approximately .01ρ, which is about twice the theoretical resistance of a ground rod inserted to an 8 foot depth. Near perfect contact at the soil-metal interface is assumed due to the weight of the vehicle. Our conclusion from this calculation is that grounding the vehicle through it's tracks is possible, if the vehicle tracks meet our conditions and assumptions. Next we will discuss the test conducted and the actual findings.

Ground Measurements

In conducting our test we gathered three pieces of data. We first determined the soil resistivity. We then determined the earth resistance of a four foot grounding rod, and finally we me attempted to measure the earth resistance of the tracked vehicle. The soil resistivity and earth resistance of the ground rod were gathered as information to be used for comparison purposes. Resistance measurements were made using a Biddle model 250302 earth tester.



Soil Resistivity Measurement

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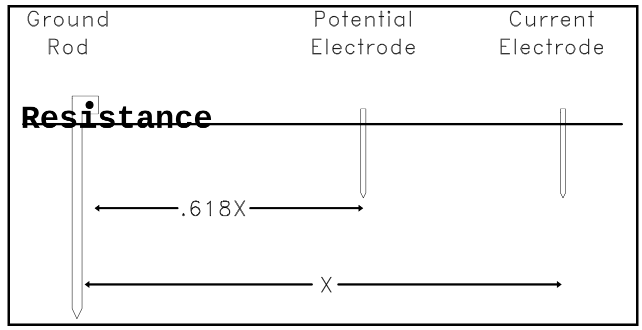
[1] *Calculation of Resistances to Ground*, H.B. Dwight, Journal of the American Institute of Electrical Engineers, December 1936, pp.1319-1328.

The soil resistivity was measured by inserting 4 electrodes each driven into the ground 10 cm with a spacing of 190.5 cm in a straight line, see figure 3. Each electrode was then connected to a separate terminal on the earth tester. The reading from the earth tester was recorded as 24.2 ohms. Using the following formula the soil resistivity was calculated.[2]

$r = 2pAR$ This expression yields the average soil resistivity to a depth A in ohm-cm. A is the distance between each electrode and R is the earth tester reading in ohms.

The soil resistivity was found to be 28,966 ohm-cm.



Ground Rod Resistance

[2] Getting Down To Earth, Biddle Instruments, April 1981, pp. 29-30.

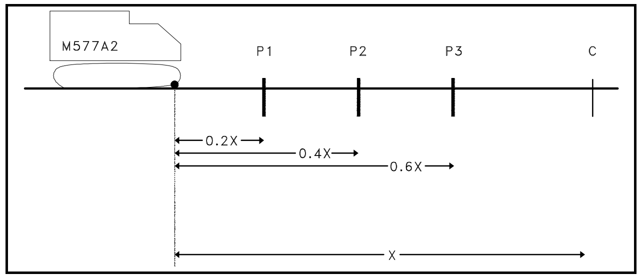
The earth resistance of a 4 foot ground rod was taken using the three electrode method. In this method the ground rod is the reference point, a current electrode is placed a distance x from the ground rod and the potential probe is placed at approximately 61.8% of x. The distance of .618x is the recommended distance to get a correct resistance measurement.[3] This distance will only provide an accurate measurement if the ground rod and the current rod are sufficiently separated such that the cylindrical shells around each do not overlap. To ensure the measurement taken is correct measurements were also taken at equal distances on either side of this position. If these measurements do not vary greatly from the .618x measurement then it can be assumed that the measurement is correct. If however the measurements on either side of the .618x show a steep slope then it can be assumed that the ground rod and the current electrode are interfering with one another and they must be further separated.

The resistance was measured by placing the current electrode 40 feet from the ground rod and the potential electrode at 21.5 ft, 24.72 ft, and 28 ft. The resistance of the grounding rod was measured to be 268 ohms, 269 ohms, and 271 ohms at each respective location. Since these values were within 1 percent of each other it was believed that they represented valid measurements. Therefore the resistance of the ground rod was recorded as the average of the 3 values or approximately 269 ohms.

[3] Biddle Manual that John has (John Please add this info)

Tracked Vehicle Ground

For the purposes of this test we used an armored command post carrier, type designation M577A2. This vehicle has 2 tracks with 11.5 ft^2 of earth contact each. Since this represents a large complex grounding system the slope method was chosen to measure the ground resistance of this system. The slope method involves taking 3 ground measurements placing the potential electrode at .2, .4, and .6 times the distance between the grounding system and the current probe, or x. From these measurements the slope of the resistance/distance curve are found using the following formula.[4]



$$m = \frac{R_3 - R_2}{R_2 - R_1}$$

Where R_1 is the resistance measurement at 0.2x, R_2 is the resistance measurement at 0.4x, R_3 is the resistance measurement at .6x, and μ is the resistance/distance slope.

Once μ is calculated a corresponding value of the P_T/x can be found in a provided table. Here P_T is the distance where the true resistance of the system can be measured, and x is the distance that the current electrode is away from the system. Since x is know P_T can be calculated and the true resistance measured by placing the potential electrode at that distance from the system.

In setting up this test we first used a value of 123 ft for x. We took measurements placing the potential electrode at 25 ft, 50 ft, and 75 ft from the vehicle. We collected measurements of 4530 ohms, 4480 ohms, and 4480 ohms respectively. These measurements gave us a value of μ equal to 0. This value was too low for the table being used. We then decided to retry the measurements placing the current probe closer to the vehicle. We next used a distance of 50 ft for x. Again we took measurements this time placing the potential electrode at 10 ft, 20 ft, and 30 ft from the vehicle. We collected measurements of 4550 ohms, 4550 ohms, and 4540 ohms. Again the values were too close together to determine a slope. We did not want to place the current probe any closer to the vehicle because we were concerned that the shells around the current probe would interfere with the

[4] Getting Down To Earth, Biddle Instruments, April 1981, pp. 44-45.

shells eliminating from the vehicle track.

At this point we decided to take some resistance measurements on the track itself. The track is made up of may pads each approximately 15 X 6.5 inches with a 6 X 4 inch rubber shoe in the center. The pads are held together by a bolt with rubber bushings surrounding it. Our initial belief in conducting this experiment was that the track pads were sufficiently bonded that they could be considered for purposes of grounding to be a continuous piece of metal. What we found out however was that the resistance between each track pad was greater than 1 Megaohm.

Conclusion

Testing of the concept of using the tracks of vehicles as a suitable technique for achieving a low resistance path to earth showed that such a low resistance path can not be achieved. The electrical resistance measurements indicated that the resistance between individual track pads on the test vehicle were very high. This high resistance prevented the track system from acting as an eclectically continuous path. This minimizes the surface area available for a connection to earth. Without a sufficient area of surface contact with the earth a good ground can not be achieved.

References

1. *Calculation of Resistances to Ground*, H.B. Dwight, Journal of the American Institute of Electrical Engineers, December 1936, pp.1319-1328.

2. Getting Down To Earth, Biddle Instruments, April 1981, pp. 29-45.

3. Biddle Manual that John has (John Please add this info)

Biography